Searching for New Physics Using Rare B Decays at the Tevatron

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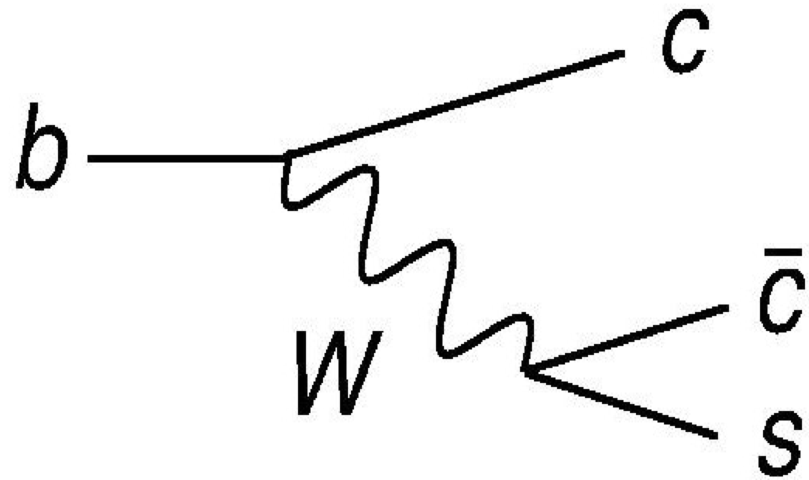
Outline

- Introduction
- Look at three analyses of rare decays and their implication on the Standard Model.
  - $B_s \rightarrow \mu\mu$
  - $B_s \rightarrow J/\psi\ \varphi$
  - Like sign dimuons
- Summary

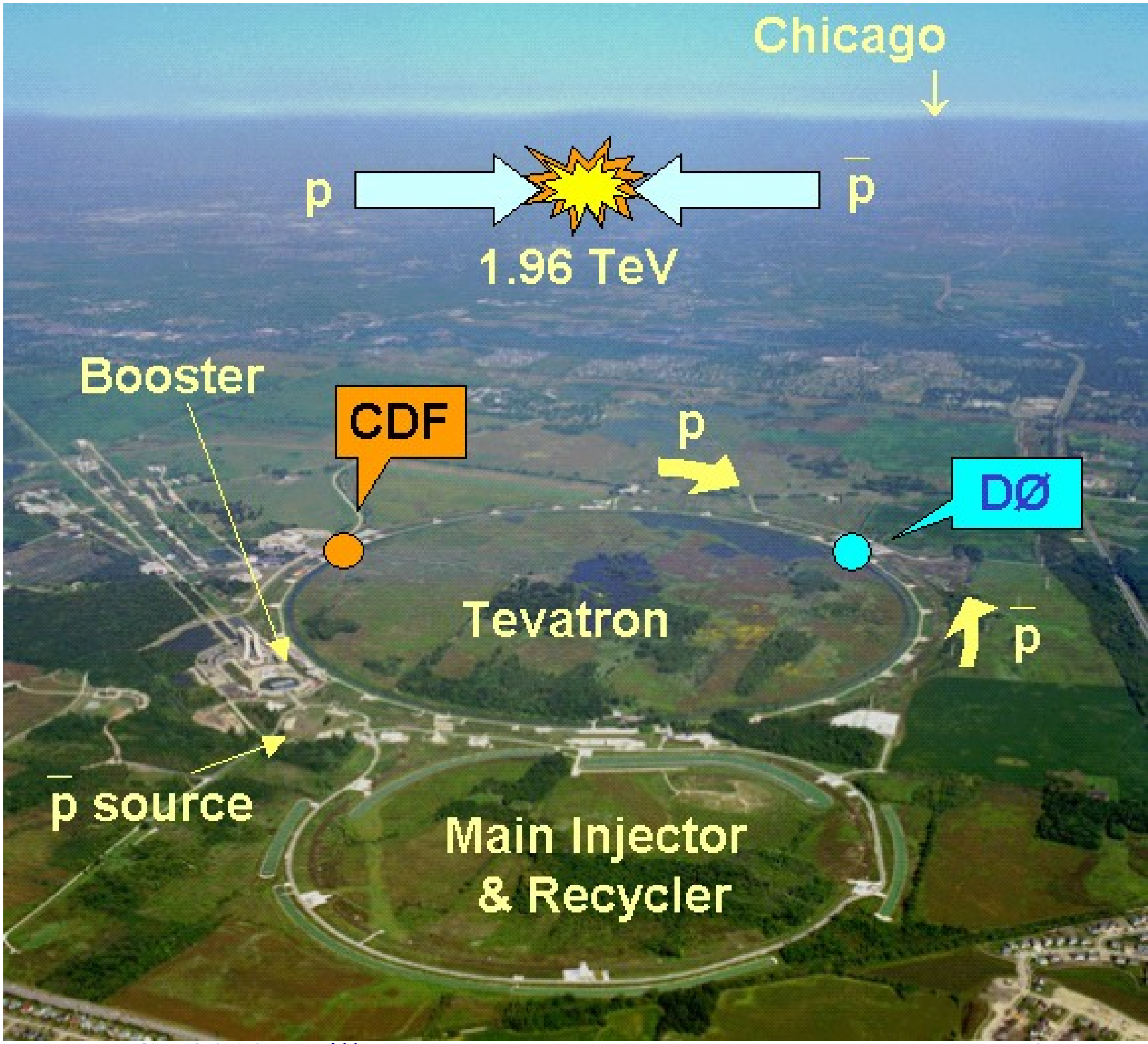
Rare Decays in B Physics

- The study of rare decays allows tests of the standard model at very high precision.
- These decays are suppressed at the tree level
- BSM physics can provide enhancements that can increase the likelihood of these decays.
- Can make new physics more obvious

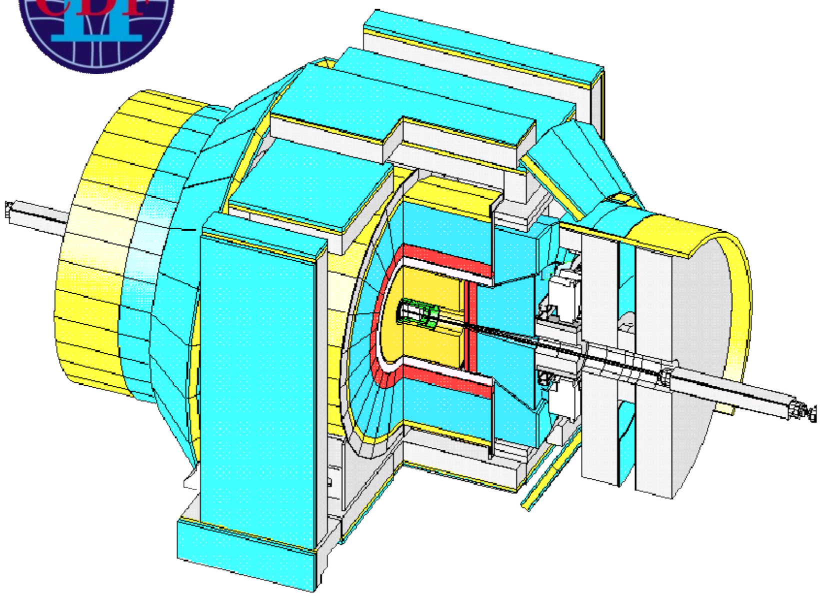


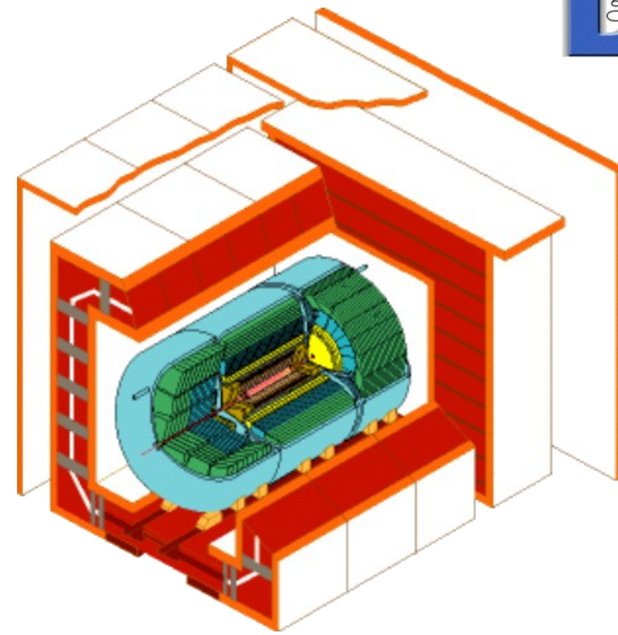
Tevatron

- No longer the highest energy particle collider
- Still provides data for high precision measurements.
- A B factory
  - Provides a large $\sigma(b\bar{b})$
  - However inelastic cross section 10^3 larger.



CDF and DØ Detectors



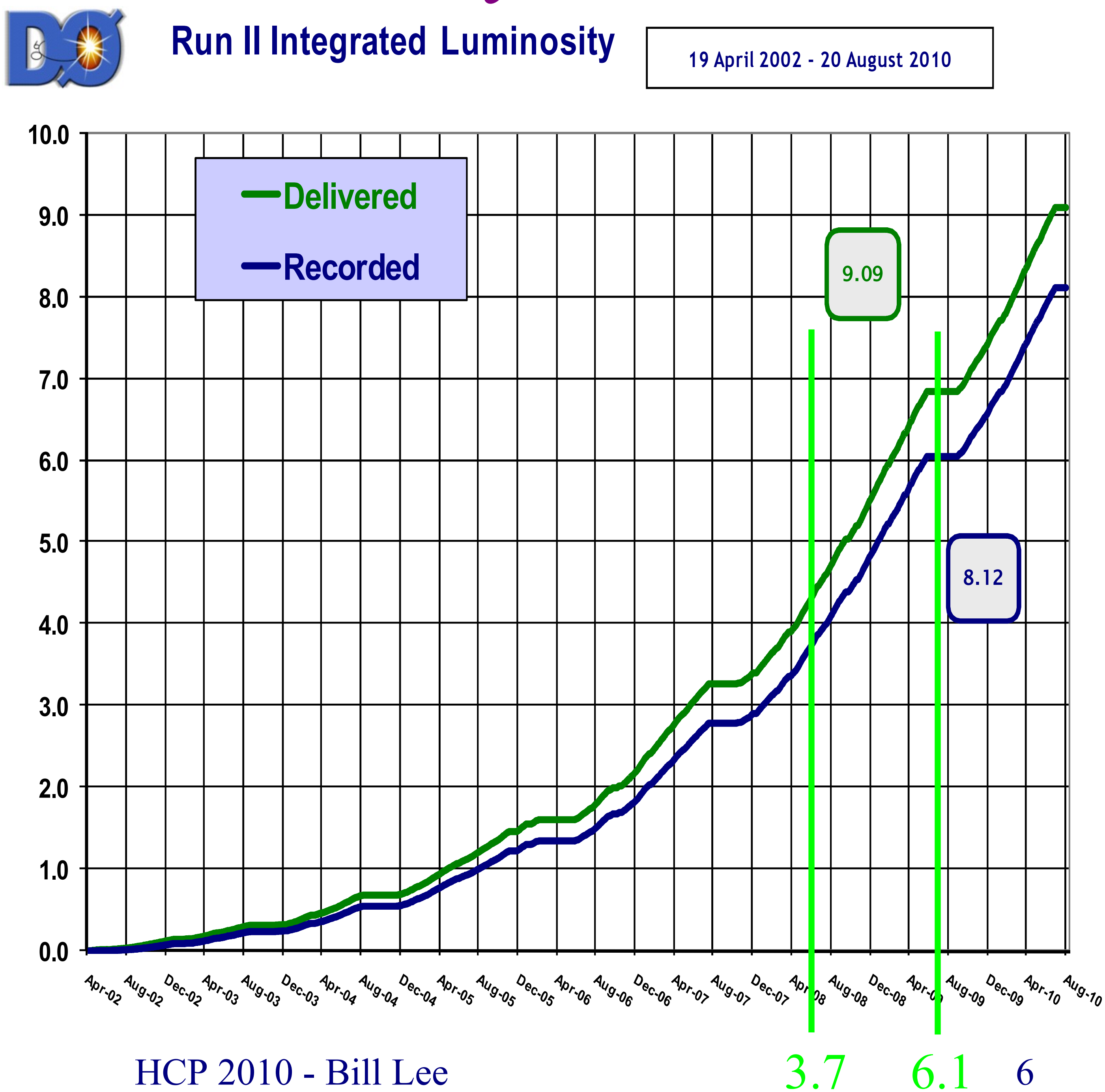


- Strong tracking system:
  - Excellent momentum resolution
  - 40 μm impact parameter resolution
- Ability to trigger on displaced tracks.
- Muon coverage to $|\eta|<1$.
- PID using dE/dx in drift chambers and ToF.

- Tracker consisting of silicon and scintillating fiber.
  - Coverage up to $|\eta|<2$.
  - Precise vertex reconstruction
- Excellent Muon ID
  - coverage to $|\eta|<2$
- Reversible magnets

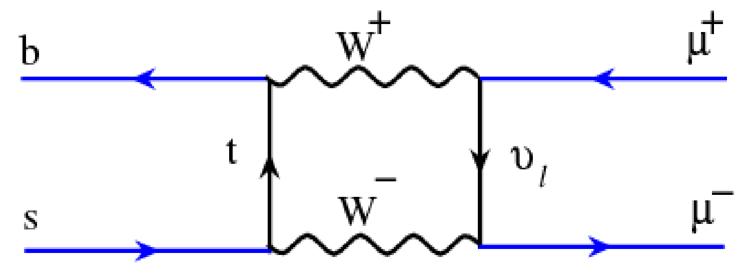
Luminosity

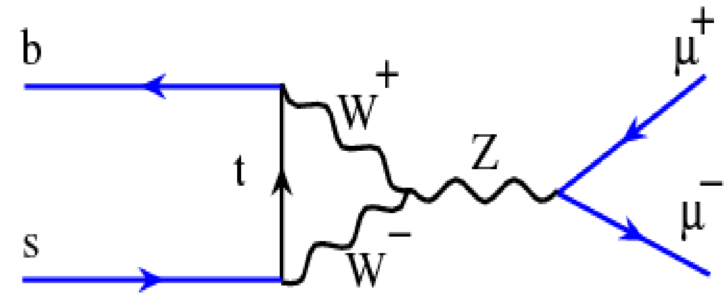
- The analyses discussed here use 3.7 to 6.1 fb^{-1} of data

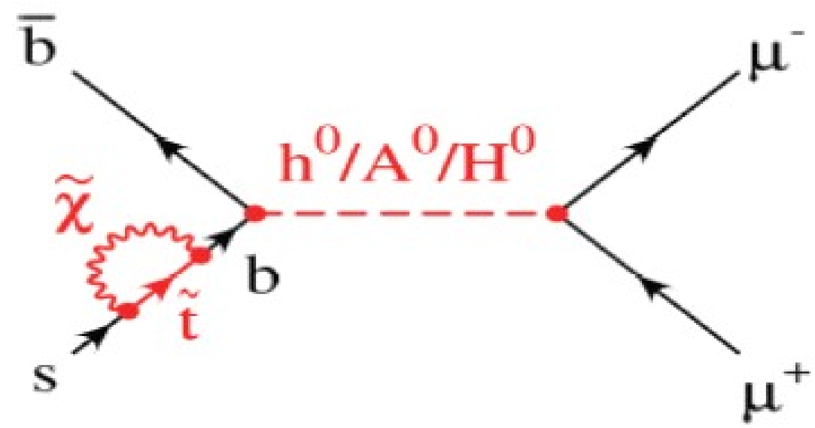


Standard Model $B_s \to \mu\mu$

- Branching fraction is very small
  - $B(B_s \to \mu\mu) = 3.6 \pm 0.3 \times 10^{-9}$
- Rate is well understood
- Clean experimental signature
- Any enhancements due to new physics might be sizable and seen clearly





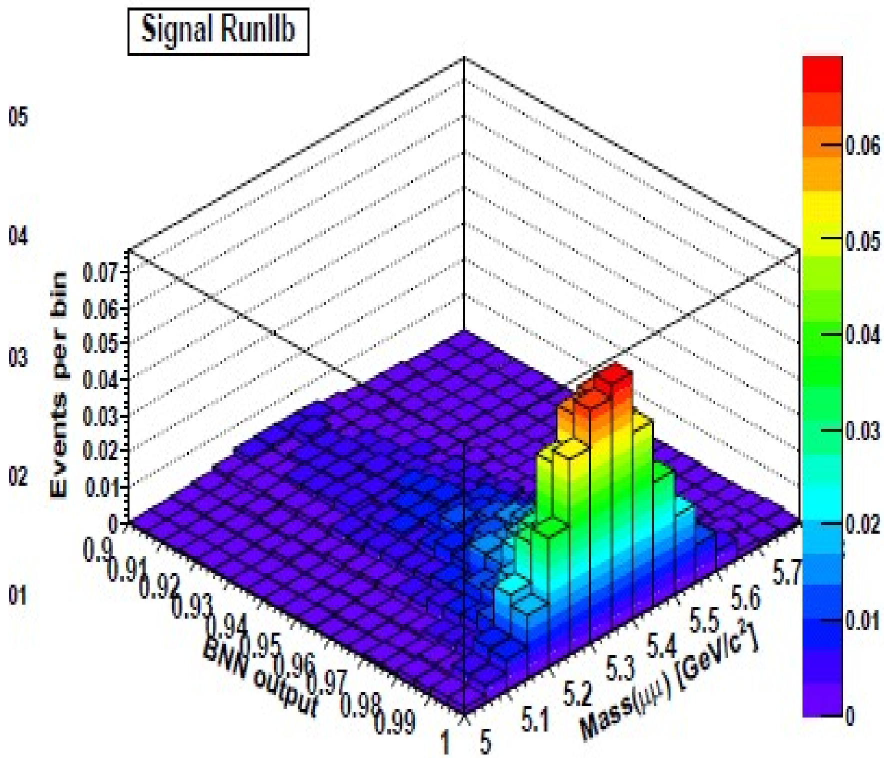


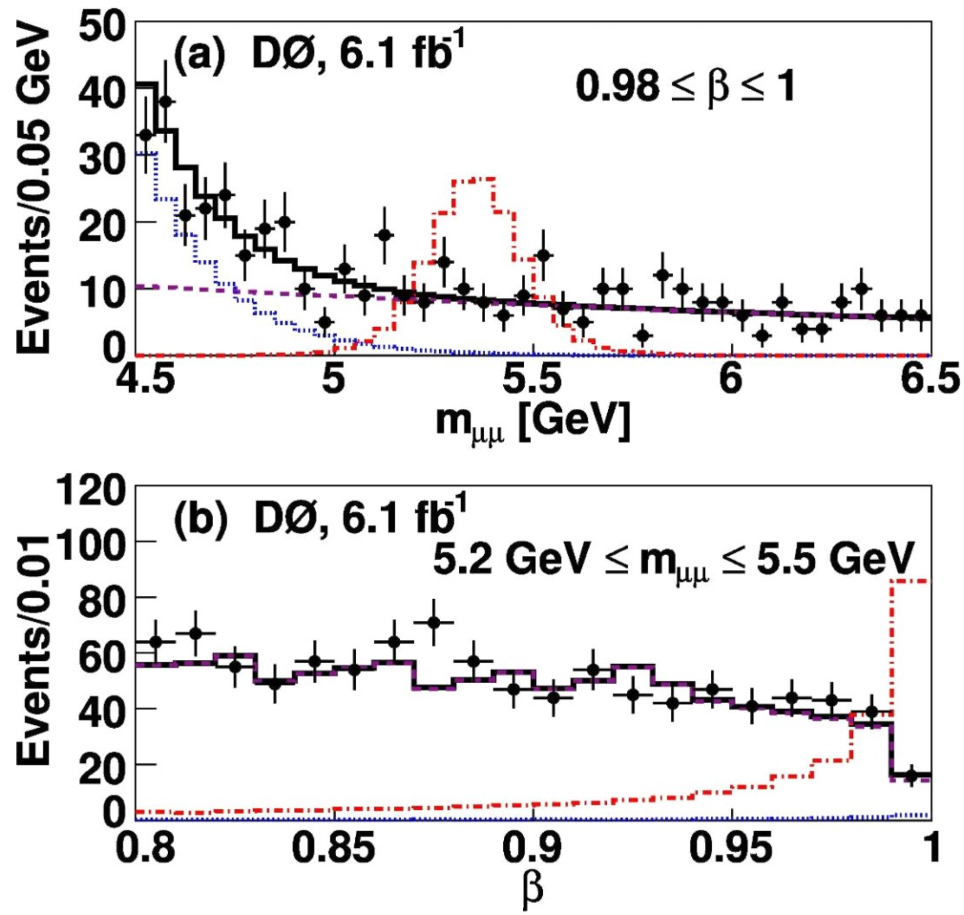
$B_s \rightarrow \mu\mu$ Analysis

- Collect Data using Dimuon triggers
- Preselect with vertex cuts, muon p_T cuts, ...
- Final selection based on a multivariate analysis to remove background
  - CDF measurement using 3 NN bins: 0.80, 0.95, 0.995
  - DØ measurement using NN in 0.9-1.0 and M(μμ) in 5.0-5.8 GeV/c^2
- Make a measurement or set limits.
  - $B^+ \rightarrow J/\psi\ K^+$ used as normalization.

DØ $B_s \to \mu\mu$ Results

2D fit to BNN and M(μμ)

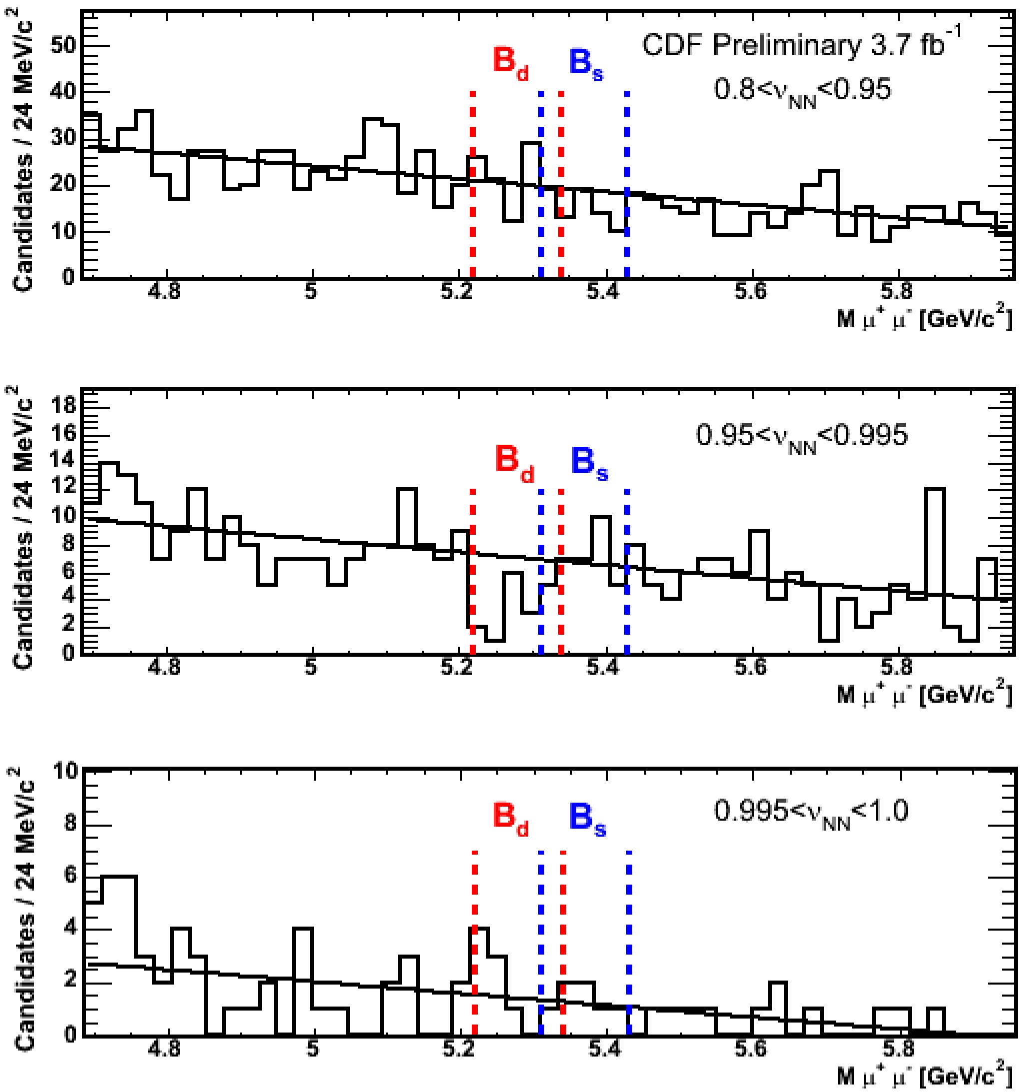




In the signal region:
51 ± 4 background events expected
55 events in data

BR < 5.1 x 10^{-8} (95% CL)
14 times the SM
Expected Limit: 3.8 x 10^{-8}

CDF B → μμ Results

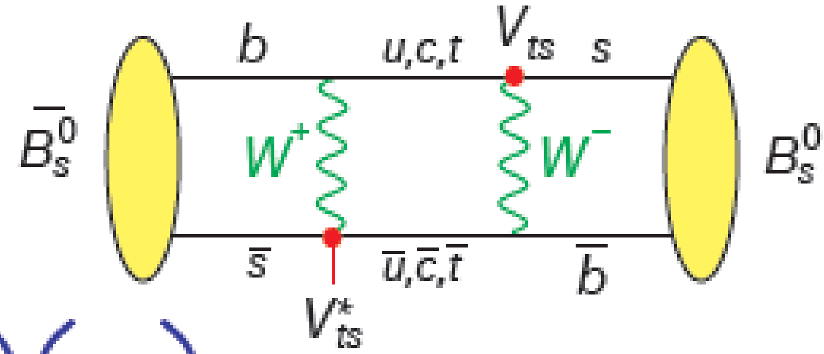


BR(B_s → μμ) < 4.3 x 10^{-8} (95%CL)

BR(B_d → μμ) < 7.6 x 10^{-9} (95%CL)

The world's best limits.

Basic B_s Mixing



$$i\frac{d}{dt}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}$$

Diagonalize

Mass Eigenstates: $|B_s^H\rangle = p\,|B_s^0\rangle - q\,|B_s^0\rangle$ $\quad |B_s^L\rangle = p\,|B_s^0\rangle + q\,|B_s^0\rangle$

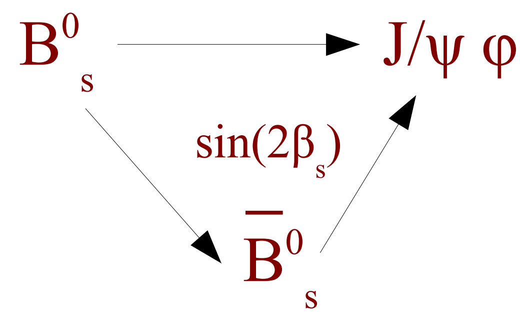
Heavy Light

If CP is conserved then q = p, so the heavy state is CP odd and the Light state is CP even.

$$\Delta m_s = M_H - M_L \sim 2|M_{12}|$$
$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \sim 2|\Gamma_{12}|\cos\varphi_s$$

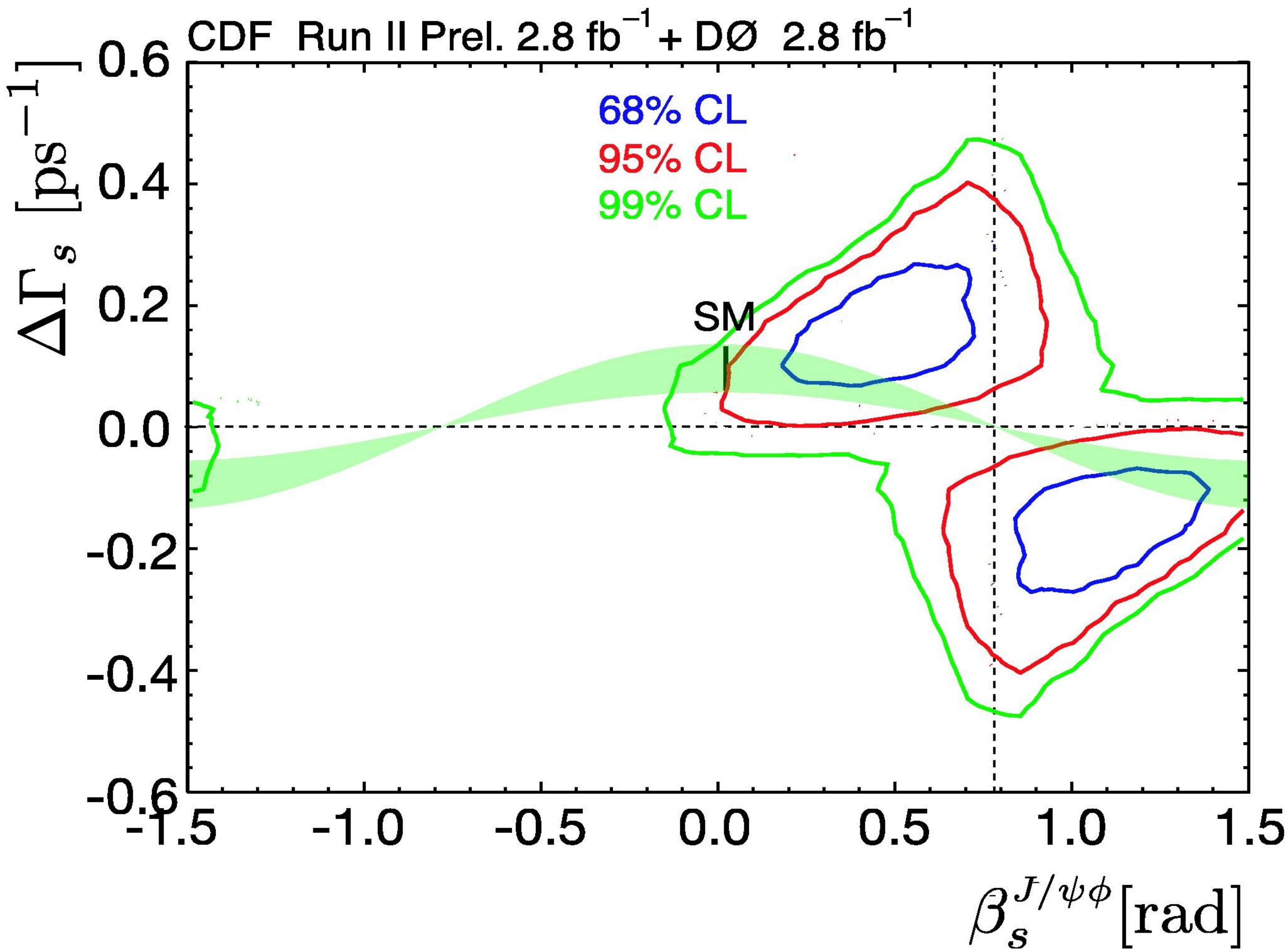
New Physics in CP Violation

Golden mode



- CP violation in the B_s system
  - Occurs through interference of diagrams with and without mixing
- In SM, CP violation phase $2\beta s$ is predicted to be very small (0.038 ± 0.002).
- However if there is new physics in the Bs mixing, then the observed phase: $\varphi_s = \varphi_{s\,SM} + \varphi_{s\,NP}$, could potentially be large.

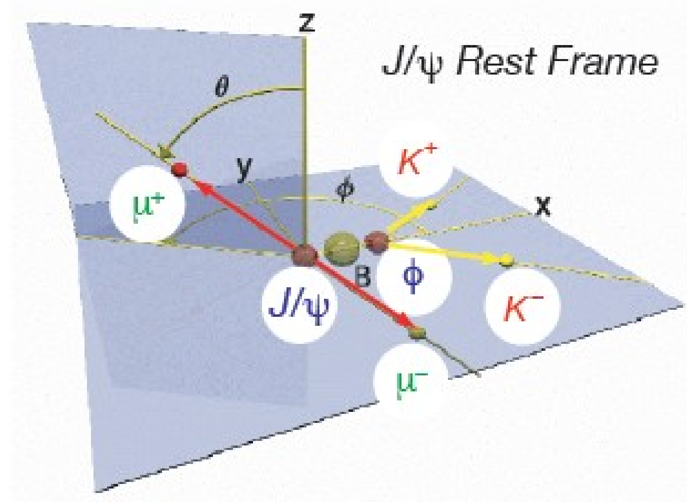
Previous CDF + DØ Result

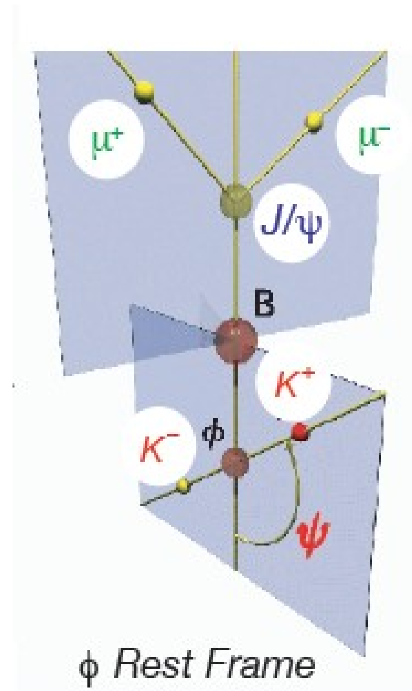


p-value for the Standard Model point is 2.0% or 2.3σ

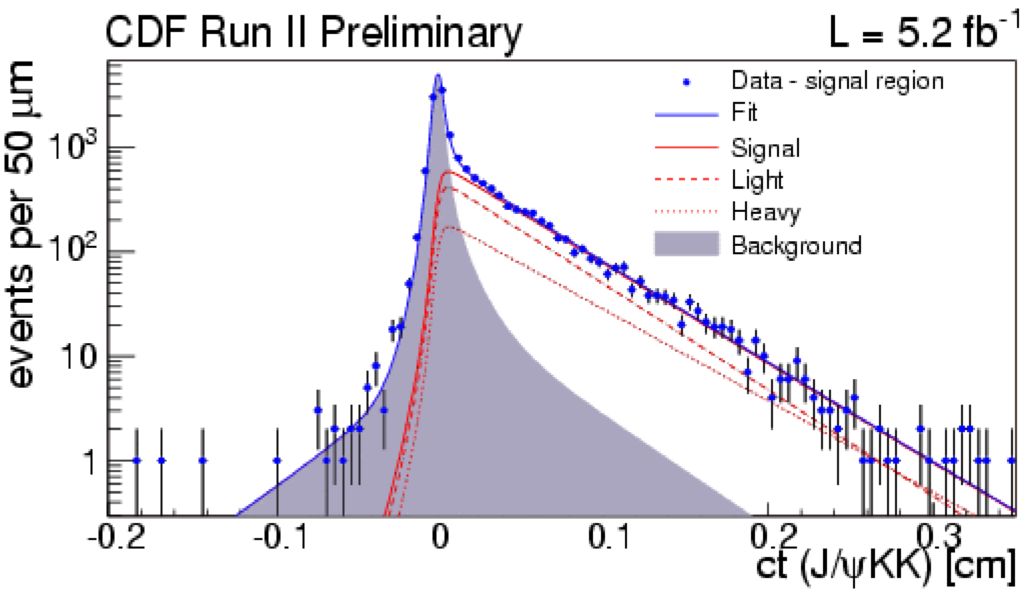
$B_s \to J/\psi\ \varphi$ Analysis

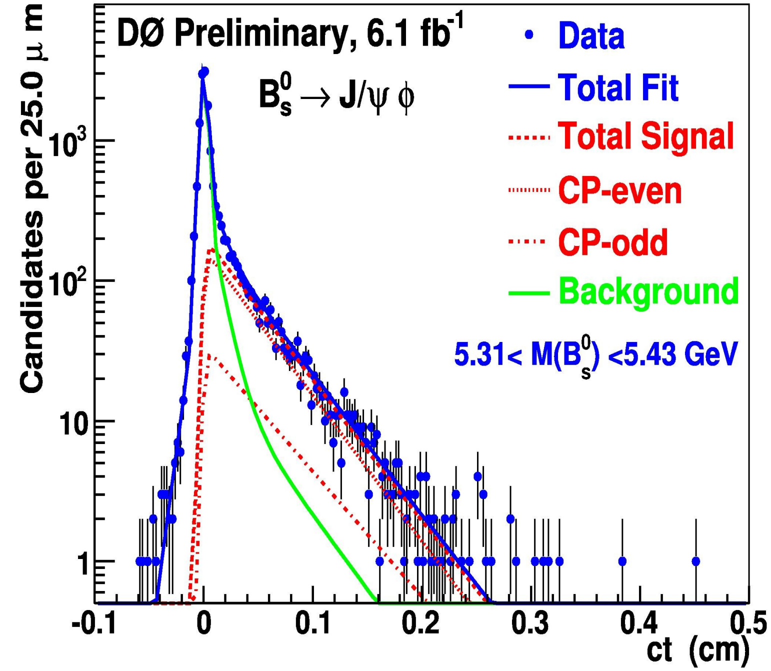
- The B_s decays in to two vector mesons that are either CP-odd or CP-even.
- Perform a time dependent angular analysis to separate CP even/odd.
- Simultaneously fit two lifetimes (heavy/light) and three angles.
  - DØ: assume that KK system is in a P-wave
  - CDF: includes S-wave component and found it to be negligible.
- Tag the B_s flavor at time of production.





$B_s \to J/\psi\ \varphi$ Lifetimes

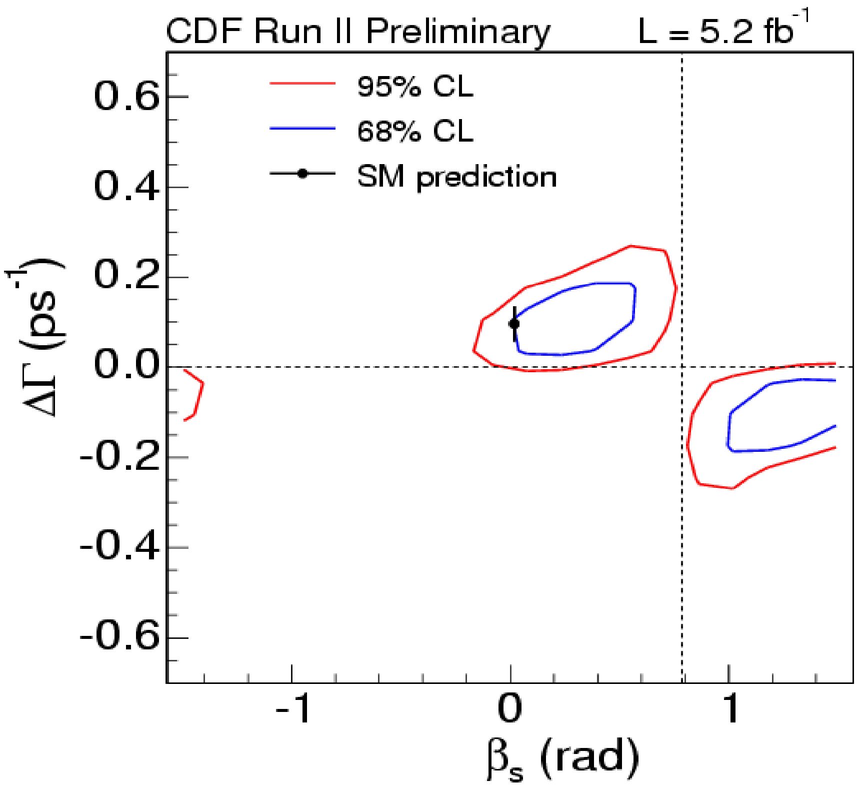


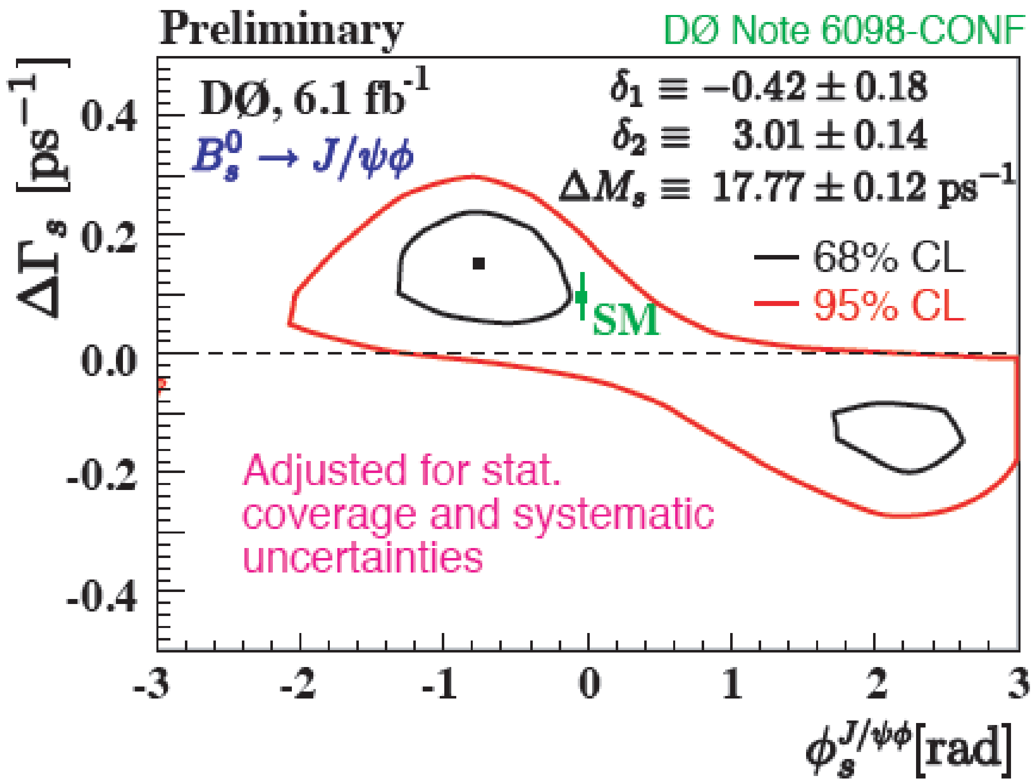


- $c\tau_s = 458.6 \pm 7.6$ (stat) $\pm$ 3.6 (syst) μm
- $\Delta\Gamma_s = 0.075 \pm 0.035$ (stat) $\pm$ 0.01 (syst) ps^{-1}
- $|A_{\|}(0)|^2 = 0.231 \pm 0.014$ (stat) $\pm$ 0.015 (syst)
- $|A_0(0)|^2 = 0.524 \pm 0.013$ (stat) $\pm$ 0.015 (syst).
- $\varphi_\perp = 2.95 \pm 0.64$ (stat) $\pm$ 0.07 (syst)
- World's most precise single measurement of the B_s lifetime and decay width difference.

- $\tau_s = 1.47 \pm 0.04$ (stat) $\pm$ 0.01 (syst) ps
- $\Delta\Gamma_s = 0.15 \pm 0.06$ (stat) $\pm$ 0.01 (syst) ps^{-1}
- $\varphi_{s\ J/\psi\ \varphi} = -0.76 \pm 0.4$ (stat) $\pm$ 0.02 (syst)

$B_s \to J/\psi\ \phi$ results

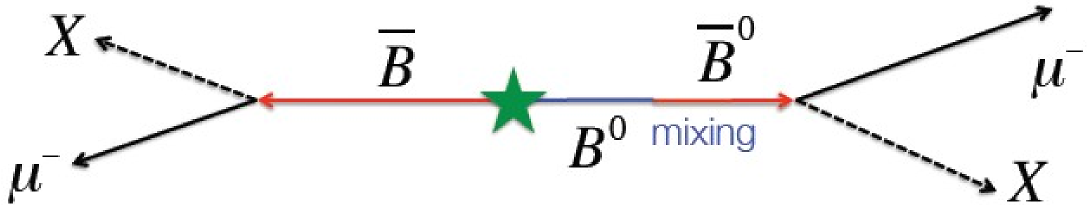




- CDF is now 0.8σ from the standard model and DØ is ~1σ from the standard model.
- The new results are closer to to SM than previous.

Another Way to Test CP Violation

- Dimuon Charge Asymmetry



  - Normal decay $\overline{B} \rightarrow \mu^- X$
  - $B \rightarrow \mu^- X$ only with flavor oscillation of B_d or B_s
- Measure CPV by using the same sign dimuon charge assymetry.

$$A_{sl}^{b} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

  - Asymmetry can occur if mixing rates are different.

A^b_{sl} at the Tevatron

- Because the asymmetry comes from meson mixing, A^b_{sl} equals the charge asymmetry a^b_{sl} of "wrong sign" semileptonic B decays:

$$a^b_{\rm sl} = \frac{\Gamma(\overline{B} \to \mu^+ X) - \Gamma(B \to \mu^- X)}{\Gamma(\overline{B} \to \mu^+ X) + \Gamma(B \to \mu^- X)} = A^b_{\rm sl} \quad = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

Semileptonic charge asymmetry

Dimuon charge asymmetry

- Both B_d and B_s are produced at the Tevatron, so both contribute to $A^b_{sl} = (0.506 \pm 0.043)\ a^d_{sl} + (0.494 \pm 0.043)\ a^s_{sl}$
- Standard model predicts $A^b_{sl} = (-0.023^{+0.005}_{-0.006})\ \%$
  - Which is negligible, so any deviation is a signal of new physics.

Charge Asymmetry Results

- Need to measure the raw asymmetry:

Inclusive muons

$$a \equiv \frac{n^+ - n^-}{n^+ + n^-}$$

Like sign dimuons

$$A \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

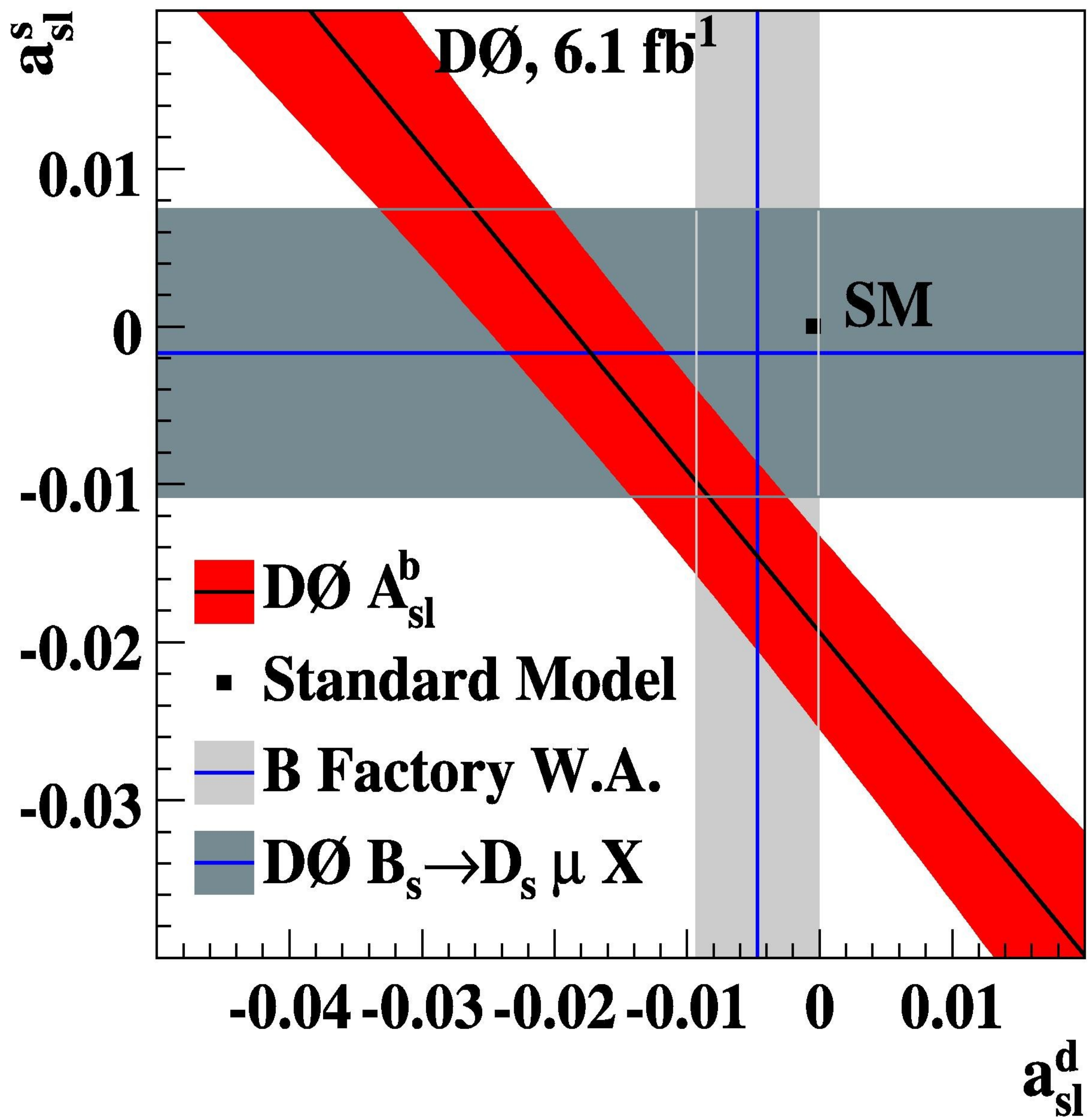
- Calculate the backgrounds to each of raw numbers from the data
  - $K^\pm$, $\pi^\pm$ decays; hadronic punch-through; muon reconstruction asymmetries; track mis-match
- Combine the above results
  - $A^b_{sl} = (0.957 \pm 0.251\ (\text{stat}) \pm 0.146\ (\text{syst}))\ \%$
- Currently statistically limited.

Charge Asymmetry Results

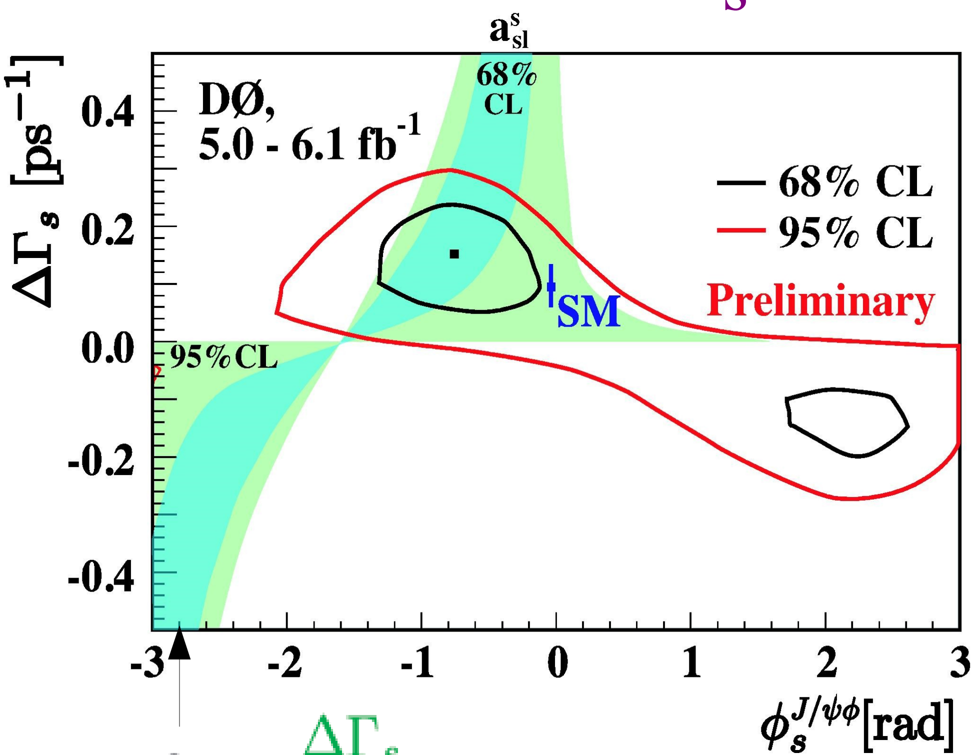
- Evidence for a dimuon charge asymmetry.
- Differs from the Standard Model

  $A^{b}_{sl} = (-0.023^{+0.005}_{-0.006})$ %

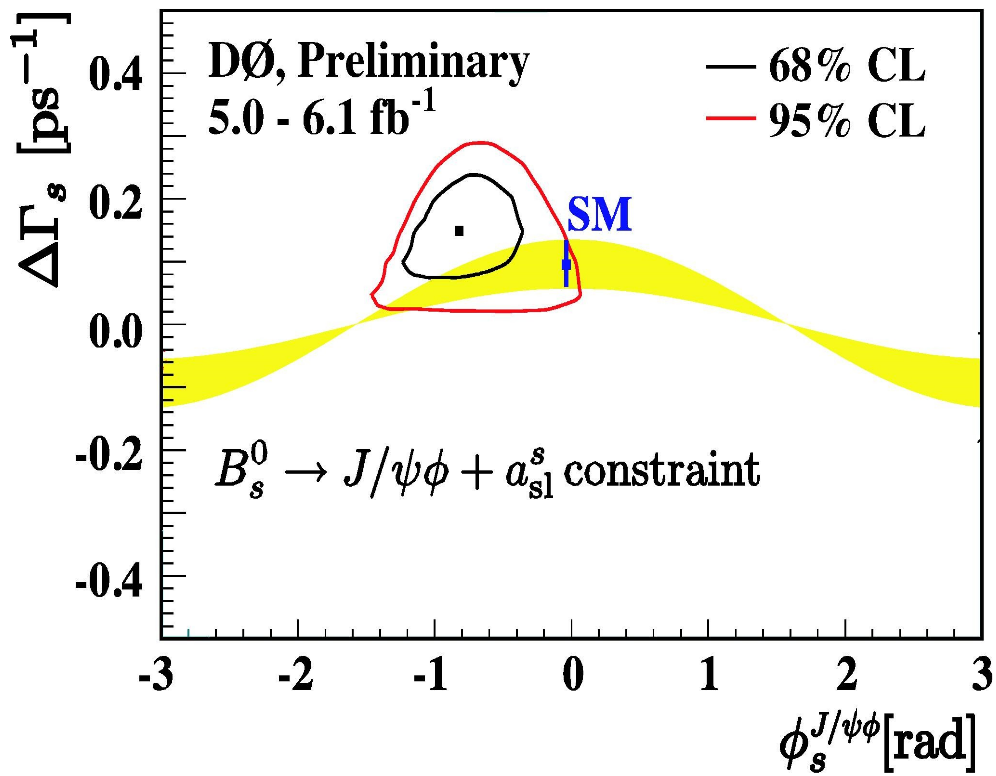
  - By 3.2σ favoring the production of matter over antimatter
- Consistent with world average of a^{d}_{sl}.



Constraining B_s Mixing Parameters



$$a_{\rm sl}^s = \frac{\Delta\Gamma_s}{\Delta M_s}\tan\phi_s$$



- Using the world average of a^d_{sl} the asymmetry result can be mapped onto the $\Delta\Gamma_s$-φ_s plane
- Combining $B_s \to J/\psi\ \varphi$ and the asymmetry result.
  - P-value of the SM point is 7%

Summary

- CDF and DØ continue to constrain the $B_s \rightarrow \mu\mu$ limit.
  - CDF has the current worlds best limit.
  - While CDF and D0 will probably not get to the standard model value by the end of the run, any enhancements from new physics can not be large.
- The CDF and DØ $B_s \rightarrow J/\psi\ \varphi$ results are now $\sim 1\sigma$ from the SM value.
  - CDF has the world's most precise single measurement of the B_s lifetime and decay width difference.
- The DØ dimuon asymmetry measurement has shown evidence for CP violation beyond the Standard Model.